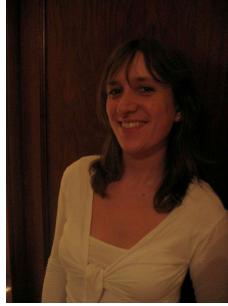


W mass and width measurements at the Tevatron

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I present a measurement of the W boson mass (M_W) and width (Γ_W) using 200 and 350 pb^{-1} of CDF Run II data respectively. The measurements, performed in both the electron and muon decay channels, rely on a fit to the W transverse mass distribution. We measure $M_W = 80413 \pm 48$ MeV and $\Gamma_W = 2032 \pm 71$ MeV which represent the world's single most precise measurements to date.

1 Introduction

The mass (M_W) and width (Γ_W) of the W boson are important parameters of the Standard Model (SM). Radiative corrections to the W propagator are dominated by Higgs and top-bottom loops, thus a precise measurement of M_W together with M_t , the mass of the top quark, place an indirect constraint on the mass of the as yet un-discovered Higgs boson, M_H . A precise measurement of Γ_W provides a stringent test of the SM prediction which is accurate to 2 MeV¹.

At the Tevatron W bosons are predominantly produced via quark anti-quark annihilation. The measurements are performed in the $e\nu$ and $\mu\nu$ decay channels which provide clean experimental signatures. The M_W and Γ_W analyses utilise 200 pb^{-1} and 350 pb^{-1} of CDF data from Run II at the Tevatron respectively.

Since neutrinos are not detected in CDF the W invariant mass cannot be reconstructed. Instead we reconstruct the transverse mass, M_T , which is defined as:

$$M_T = \sqrt{2p_T^\ell p_T^\nu (1 - \cos \phi_{\ell\nu})} \quad (1)$$

where p_T^ℓ is the transverse momentum (p_T) of the charged lepton, p_T^ν is the p_T of the neutrino and $\phi_{\ell\nu}$ is the azimuthal angle between the charged lepton and the neutrino. p_T^ν is inferred from the transverse momentum imbalance in the event.

A Monte Carlo simulation is used to predict the M_T distribution as a function of M_W and Γ_W . These predictions are fitted to the data with a binned maximum-likelihood fit in order to extract M_W and Γ_W . The fit for M_W is performed in the region around the peak of the distribution: 65–90 GeV. The fit for Γ_W is performed in the high M_T tail region: 90–200 GeV, which is still sensitive to the Breit-Wigner line-shape but less sensitive to the Gaussian detector resolutions. These line-shape predictions depend on a number of production and detector effects. The most important effects are described in this document and all the systematic uncertainties are summarised at the end.

2 Monte Carlo Simulation

A dedicated parameterised Monte Carlo simulation is used to generate the M_T templates used in the fits. The W p_T spectrum is modelled with RESBOS² and QED corrections for one photon emission are simulated with Berends and Kleiss³ and WGRAD.⁴ Systematic uncertainties arise from non-perturbative QCD parameters affecting the W p_T spectrum and considerations of the emission of a second photon from the final state charged lepton. Parton distribution functions (PDFs) affect the acceptance and kinematics of decay products. The templates are generated with the CTEQ6M⁵ PDFs and their error sets are used to estimate the PDF uncertainty.

The detector response model is tuned to $Z \rightarrow \ell\ell$ and $W \rightarrow \ell\nu$ data as well as a full GEANT Monte Carlo simulation of the CDF detector.

3 Lepton Calibration: Scales and Resolutions

The muon momentum is measured in a cylindrical drift chamber. The scale and resolution of the momentum are calibrated using the resonance peaks in $J/\Psi \rightarrow \mu\mu$, $\Upsilon(1S) \rightarrow \mu\mu$ and $Z \rightarrow \mu\mu$ events utilising the precisely measured world average masses of these particles.¹ The J/Ψ sample has sufficient statistics to verify the linearity of the momentum scale by studying its variance as a function of muon p_T . Combining all three measurements enables an accuracy of 0.021% on the momentum scale.

The electron energy is measured in the calorimeter. The electron momentum is also measured in the drift chamber^a, thus the well calibrated momentum measurement is used to calibrate the calorimeter scale (response) and resolution using the ratio between the electron energy measured in the calorimeter and the track momentum (E/p) in $W \rightarrow e\nu$ events. The scale and resolution can also be obtained independently from the mass peak in $Z \rightarrow ee$ events. The two measurements are combined to give a calorimeter scale measurement accurate to 0.034%.

4 Hadronic Recoil Calibration

The neutrino p_T is determined from the missing transverse energy, \cancel{E}_T , in the detector. A recoil vector, \vec{U} , is defined as the vector sum of transverse energy over all calorimeter towers, excluding those surrounding the lepton. The \cancel{E}_T is then defined as $-(\vec{U} + \vec{p}_T^\ell)$. The recoil has contributions from initial state gluon radiation from the incoming quarks, underlying event energy and final state photon radiation from the charged lepton. The recoil is represented by a parameterised model, which is tuned in $Z \rightarrow \ell\ell$ events. The model parameters are found from the Z data and applied to the W data. The systematic uncertainties on M_W and Γ_W come from the uncertainties on the model parameters due to the limited statistics in the Z data.

^aSince the mass of the electron is negligible the true momentum and energy values are the same. However collinear photon radiation from the electron which is clustered back into the energy measurement can decrease the track momentum measurement. These effects are well modelled in the simulation.

Table 1: Uncertainties for the W mass (left) and W width (right). The third column lists the uncertainties that are common between the electron and muon channels.

ΔM_W [MeV]	e	μ	C	$\Delta \Gamma_W$ [MeV]	e	μ	C
Lepton Scale	30	17	17	Lepton Scale	21	17	12
Lepton Resolution	9	3	0	Lepton Resolution	31	26	0
Recoil Scale	9	9	9	Simulation	13	0	0
Recoil Resolution	7	7	7	Recoil	54	49	0
Lepton ID	3	1	0	Lepton ID	10	7	0
Lepton Removal	8	5	5	Backgrounds	32	33	0
Backgrounds	8	9	0	$p_T(W)$	7	7	7
$p_T(W)$	3	3	3	PDF	16	17	16
PDF	11	11	11	QED	8	1	1
QED	11	12	11	M_W	9	9	9
Total Systematic	39	27	26	Total Systematic	78	70	23
Statistical	48	54	0	Statistical	60	67	0
Total	62	60	26	Total	98	97	23

5 Backgrounds

Backgrounds have different M_T distributions to $W \rightarrow \ell\nu$ events, therefore the M_T shape must be added to the Monte Carlo templates when fitting to the data. Electroweak backgrounds consist of $Z \rightarrow \ell\ell$ events where one of the leptons goes undetected and $W \rightarrow \tau\nu$ and $Z \rightarrow \tau\tau$ events where the τ decays to an electron or muon. These backgrounds are found using Pythia⁶ Monte Carlo samples of W and Z events, passed through a full GEANT simulation of the CDF detector. Non-electroweak backgrounds consist of multi-jet events, where one jet fakes or contains a lepton and the other is sufficiently mis-measured to produce \cancel{E}_T , and (in the muon channel only) kaons that decay to muons within the volume of the drift chamber. In the latter case the resulting reconstructed track contains a kink that can produce a fake high measured p_T and \cancel{E}_T . The multi-jet background normalisations are found by fitting the low \cancel{E}_T distribution where this background dominates. The M_T distributions are found by reversing certain lepton identification cuts. The kaon background is found by fitting the high tail of the track fit χ^2 distribution where this background is large. The M_T shape is found by reversing an impact parameter cut.

6 Results

The systematic and statistical uncertainties for M_W and Γ_W are summarised in Table 1. Figure 1 shows the M_T fits for M_W in the muon and electron decay channels. The fitted M_W values are combined together with fits to the charged lepton p_T and \cancel{E}_T distributions to give $M_W = 80413 \pm 48$ MeV, the world's most precise single measurement. This result increases the world average central value by 6 MeV and reduces the uncertainty by 15%. The updated world average impacts the global precision electroweak fits, reducing the preferred M_H by 6 GeV to 76^{+33}_{-24} GeV. The 95% CL upper limit on M_H is 144(182) GeV with(out) the LEP II direct limit included.^{7,8} Figure 2 shows the M_T fits for Γ_W in the muon and electron decay channels. The results are combined to give the final result $\Gamma_W = 2032 \pm 71$ MeV, the world's most precise single measurement, which is in good agreement with the SM prediction. This result reduces the world average central value by 44 MeV and uncertainty by 22%.

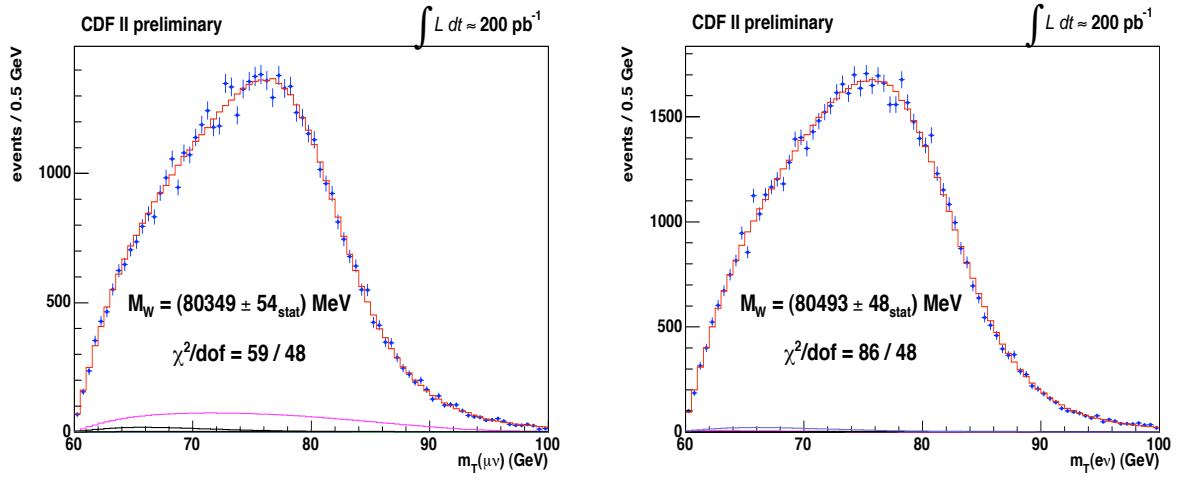


Figure 1: Transverse mass fits for M_W in $W \rightarrow \mu\nu$ (left) and $W \rightarrow e\nu$ (right) events. The fit is performed in the region 65–90 GeV.

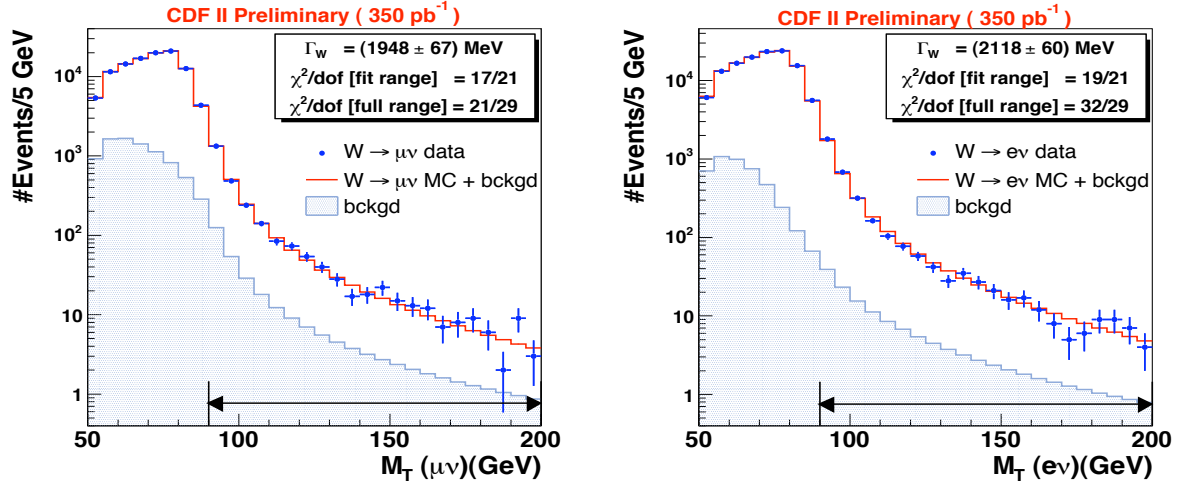


Figure 2: Transverse mass fits for Γ_W in $W \rightarrow \mu\nu$ (left) and $W \rightarrow e\nu$ (right) events. The fit is performed in the region 90–200 GeV.

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